Scientia Iranica, Vol. 9, No. 3, pp 248–254

SCIENTIA
IRANICA

Measuring Productivity Indexes and Efficiency in the Container Terminal at Port Rajaei

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The purpose of this study is to determine productivity indexes and productive efficiency in the container terminal at Port Rajaei of the Ports and Shipping Organization (PSO) in Iran. Parametric and nonparametric approaches are used to construct a frontier to be used as a yardstick of productive efficiency for the period of 1994-1999. Moreover, indexes with respect to the goals are identified and, then, are measured for the period of 1990-1999.

INTRODUCTION

A considerable amount of research has centered on the measurement of productivity. Over the last two decades, much interest has been focused on traditional productivity measures, in which, productivity may be simply defined as the ratio of what is given to the system and what is produced, or the ratio of output to input. Traditionally, productivity measures have been categorized as either partial or total.

Partial productivity measures represent the ratio of output to one input or some portion of inputs whereas total productivity compares all outputs to all inputs. In recent years, an increasing number of studies have concentrated on manufacturing, despite the growing importance of services. Although traditional productivity measures are appropriate for manufacturing industries, it is not appropriate for service industries owing to the inherent characteristics of services.

There are two different approaches for estimation of efficiency in the service industry.

Parametric Approach

The stochastic frontier production, proposed independently by Aigner, et al. [1] and Meeusen and van den Broeck [2], has been considered and applied or modified in a number of studies, (e.g., [3-5]). The stochastic involved the estimation of parameters of the stochastic frontier production function and the mean technical efficiency for firms in industry. Jondrow et al. [6] presented two predictors for the firm effect for an individual firm on the assumption that the parameters of the frontier production function were known and cross sectional data were available for sample firms. Schmidt and Sickles [7] considered a number of methods of predicting individual firm effects. Waldman [5] investigated the properties of a predictor for firm technical efficiencies proposed by [6].

There are a very large number of studies applying frontier production function including [8-11].

Nonparametric Approach

In nonparametric analysis of production efficiency (DEA method), the focus of attention is on the production frontier. That is, maximum possible outputs that can be produced from given quantities of a set of inputs. The indicator of productivity, also called technical efficiency, gives the distance between the frontier and the input-output vector of actual production in a given firm at a given period of time. It is considered as particularly appropriate for service industries. It consists of a linear programming technique for constructing a nonparametric piecewise linear envelop to the observed data [12].

The nonparametric method is based upon Farrell's original article [13] as well as extensions of his work initiated by Charnes, Cooper and Rhodes [14]. They introduced the ratio definition of efficiency. DEA

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(Data Envelopment Analysis) has been widely used in previous efficiency studies of service industries including [9,10,15,16].

DETERMINING PRODUCTIVITY INDEXES

Productivity indexes must be determined with respect to the company goals, so it is assured that what is measured is directed to the goals. The first step is to identify brilliant goals. The goals must be quantifiable, available, measurable and related to the success factors of the company [1,20].

The next step is to identify the approaches used to reach the goals. In this approach, major productivity indexes can be identified and these measurements will make possible the judgment regarding the impact of any decision on these goals.

Following is an example in this regard.

Goal 1: Increasing Container Handling

First approach: Increasing the number of containers to be handled,

First index: $\dfrac{\text{Number of containers loaded / unloaded}}{\text{Annual working days}}$

It must be noted that there are two kinds of container: 20 feet and 40 feet. Regardless of the number of 20 feet and 40 feet containers, TEU (Twenty Equivalent Unit) can be used as the equivalent number of 20 feet containers.

Second approach: Increasing handling rate;

Second index: Time consumed for handling one container;

Third approach: Increasing competition in regional ports;

Third index:

$$\frac{\text{Total tonnage of container cargo from/to Iran}}{\text{Total tonnage of container cargo handled in the region}}$$

Goal 2: Improving Services and Standards

First approach: To decrease average ship waiting time;

First index: Average waiting time;

Second approach: To decrease average time of container handling;

Second index:

$$\frac{\text{Time consumed for handling one container}}{\text{Standard time}}.$$

Standard time for container handling is 3 minutes. It is the time taken for a gantry crane to unload a container from a ship and load it into a trailer.

PARAMETRIC METHOD

Consider the frontier production function

$$Y_{it} = X_{it}\beta + \varepsilon_{it}, \tag{1}$$

and:

$$\varepsilon_{it} = \nu_{it} - v_i, \tag{2}$$

where Y_{it} denotes the appropriate function (e.g., logarithm) of the production for the ith sample firm ($i = 1, 2, ..., n$) in the tth time period; X_{it} is a (1^*k) vector of appropriate functions of the inputs associated with the ith sample firm in the tth time period; β is a (1^*k) vector of the coefficients for the production function; ν_{it} is a random variable which is assumed to be independent and identically distributed as $N(0, \sigma_v^2)$. v_i is a random variable which is assumed to be independent and identically distributed as a non-negative random variable of $N(\mu, \sigma^2)$. σ_v^2 is the variance of v_{it} and σ^2 is the variance of v_i . In addition, it is assumed that ν_{it} and v_i-random variables are independently distributed from the input variables in the model. ε_{it} is random error for the ith sample firm ($i = 1, 2, ..., n$) in the tth time period [19].

The density function for $v_i, f_{vi}(v)$ is defined by:

$$f_{vi}(v) = \frac{\exp[(-1/2)(v-\mu)^2/\sigma^2]}{(2\pi)^{1/2}\sigma[1-\varphi(-\mu/\sigma)]}, \qquad v > 0, \tag{3}$$

where $\varphi(.)$ denotes the distribution function of the standard random variable [19].

The distribution of the non-negative firm-effect random variables is that suggested by Stevenson [20], which is the generalization of the half-normal distribution (in which $\mu = 0$). Pitt and Lee [21] and Schmidt and Sickles [7] considered the special case of this model, in which the firm effects had half-normal distribution. George E. Battese [19] defined the technical efficiency of a given firm as the ratio of its mean production to the corresponding mean production if the firm effect was zero.

If the frontier production Functions 1 and 2 are defined directly in terms of the original units of production, then the technical efficiency of the ith firm is:

$$TE_i = (X_i\beta - v_i)(X_i\beta)^{-1}, \tag{4}$$

where X_i is the mean of the input levels for the ith firm.

If the frontier production Functions 1 and 2 are defined for the logarithm of production, then the production for the ith firm in the tth period is $\exp(Y_{it})$. Thus the measures of technical efficiency for the ith firm is:

$$TE_i = \exp(-v_i), \quad (5)$$

This measure of technical efficiency is equivalent to the ratio of the production for the ith firm in any given period t, $\exp(Y_{it}) = \exp(X_{it}\beta + \nu_{it} - v_i)$, to the corresponding production value if the firm efect v_i was zero, $\exp(X_{it}\beta + \nu_{it})$ [19].

The mean technical efficiency of firms in industry that corresponds to the measure of Equation 5 is:

$$TE = \frac{1 - \varphi(\sigma - \mu/\sigma)}{1 - \varphi(-\mu/\sigma)}[\exp(-\mu + (1/2)\sigma^2)], \quad (6)$$

where $\mu = 0$,

$$TE = 2[1 - \varphi(\sigma)]\exp(\sigma^2/2). \quad (7)$$

In this study, in order to estimate the stochastic production function, the production function is represented by the following Cobb-Douglas function [10]:

$$\text{Ln } Y_t = \beta_0 + \beta_1 \text{Ln}(x_{1t}) + \beta_2 \text{Ln}(x_{2t}) + \varepsilon_{it}. \quad (8)$$

In this article, Y_t represents the output or number of containers that are loaded/unloaded at a container terminal in year $t (t = 1994-1999)$, x_{1t} the total capital costs in year t and x_{2t} the total labor costs in year t. $\varepsilon_{it} = \nu_{it} - v_i, \nu_{it}$ is the usual random term, where v_i, independent of ν_{it}, is obtained by truncating the normal distribution above zero and representing the firm-specific degree of inefficiency. β_0, β_1 and β_2 are estimated by least-squares method.

NONPARAMETRIC METHOD

As a representative of the nonparametric approach, the DEA method introduced by Charnes, Cooper and Rhodes [14] was adopted, which uses linear programming techniques to envelope observed input-output vectors as tightly as possible without requiring a period of specification of functional forms. DEA requires only an assumption of convexity of the production possibility set and disposability of inputs and outputs. It employs a postulated minimum extrapolation from observed data in the application [22].

One of the main advantages of DEA is that it allows for consideration of several inputs and outputs at the same time.

In this approach, technical efficiency is defined as minimum input for any particular combination of outputs. Farrel provided a methodology by which technical efficiency could be measured against an efficiency frontier, assuming constant returns to scale. The production frontier obtained is the boundary of the free disposal convex cone of the data set [9].

Farrell original approach of computing the efficiency frontier as a convex hull in the input coefficient space was generalized to multiple outputs. Furthermore, it was reformulated into calculating the individual input-saving efficiency measures by solving LP problems for each unit by Charnes et al. [10] under the CRS (Constant Returns to Scale). Fare et al. [23], Banker et al. [12] and Byrnes et al. [24] extended this approach to the case of VRS (Variable Returns to Scale) and developed corresponding efficiency measures [9].

In the Farrel approach, the efficiency of a micro unit is measured relative to the efficiency of all other micro units subject to the restriction that all micro units are on or below the frontier [9].

Depending on the assumption about scale properties of the production set, three different input-saving measures may be derived. One measure will be calculated under the assumption of CRS and another under VRS. In addition, an input-saving measure will be calculated under the assumption of non-increasing returns to scale.

The measure under the assumption of CRS is illustrated in Figure 1 with one output y and one input x.

The frontier technology is represented by the ray from the origin through point B. In this case only B is efficient, since B is on the frontier and the input-saving efficiency measure is calculated by $X_B/X_B = 1$. Correspondingly, the efficiency of A is calculated as $X_H/X_A < 1$. The LP problem that must be solved for different micro units under CRS is:

$$\max E_c = \sum_{r=1}^{S} U_r Y_{r0},$$

$$\text{s.t.} \quad \sum_{i=1}^{m} V_i X_{i0} = 1,$$

$$\sum_{r=1}^{S} U_r Y_{rj} - \sum_{i=1}^{m} V_i X_{ij} =< 0, \quad j = 1, 2, ..., n$$

$$U_r, V_i >= 0, \quad (9)$$

where n is the number of micro units $(j = 1, 2, ..., n)$, m is the number of inputs $(i = 1, 2, ..., m)$, s is the number of outputs $(r = 1, 2, ..., s)$, Y_{rj} denotes the level of output r for unit j, X_{ij} denotes the level of input i for unit j, U_r and V_i are the weights for output r and input i, respectively and U_r and V_i are decision variables obtained in the LP solution. Thus, for each micro unit, an LP problem is solved by maximization

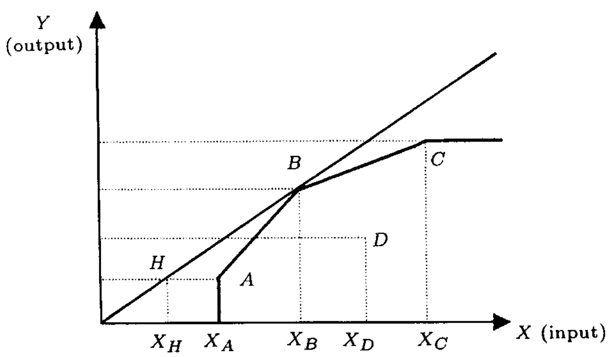

Figure 1. An illustration of DEA efficiency measures. A, B, C and D are different micro units with one input X_A, X_B, X_C and X_D and one output Y_A, Y_B, Y_C and Y_D, respectively.

of the weighted sum of outputs for micro unit k, with regard to the restriction that the weighted sum of inputs equals 1 for this micro unit and that for all micro units ($j = 1, 2, ..., k, ..., n$) the weighted sum of outputs, minus the weighted sum of inputs, are less than or equal to 0. The last restrictions mean that all micro units are on or below the frontier. The value of objective function is efficiency [9,15].

In this article, the appropriate programming models were formulated for data envelopment analysis (DEA) under constant return to scale assumption and applied to time series data set from a container terminal covering the period 1994-1999. It must be noted that while the CRS assumption permits the use of the standard linear programming method, the VRS assumption requires a mixed integer programming.

This study uses a data set consisting of annual observations for a container terminal. A two-input single-output production technology is considered. The single output is the number of handled containers. The two inputs are labor costs and capital costs, so six LP problems are planned and solved. The value of objective function is efficiency.

AN EMPIRICAL ANALYSIS

Table 1 gives a description of the main data used in this study. Some data come from annual operation list of ports and some of them are calculated [25].

The output variable is the number of containers that are handled. The real output in a given year is measured by taking the number of handled containers (20 feet and 40 feet).

Labor costs and capital costs are two main inputs and labor costs are measured by the annual working days used during each year.

Capital costs include annual cost and depreciation. These are considered for all of the equipment that is used in the container terminal of Port Rajaei. For determining annual uniform cost, the following formula is used:

$$A = P(A/P, i\%, n),$$

where A denotes annual cost, P is present value, i is interest rate and n is useful life. Linear depreciation rate is calculated by $(I - S)/n$ where I denotes initial investment and S denotes salvage value.

For determining productivity indexes, fuel, electricity, preventive and maintenance costs were required; since these values were not available, some estimates were used. For example, according to the World Bank reports, electricity consumption for each gantry crane is 450 kw/hour and fuel consumption for trailer, toplift and transtainer are 10 lit/hour, 18 lit/hour, 20 lit/hour,

Table 1. Costs and number of handled containers in Port Rajaei.

		Costs (Million Rials)				
Year	Container Handling 1000 TEU	Capital	Labor	Fuel Electricity	Preventive Maintenance	Total Million Rials
1990	11	54.96	115.08	0.8	20.7	191.5
1991	20	54.96	115.08	1.45	20.7	192.1
1992	51	54.96	143.85	3.91	20.7	223.4
1993	44	73.5	197.28	3.15	20.7	294.6
1994	107	277.55	287.7	177.6	25.2	768.05
1995	100	302.27	328.8	165	114.08	910.15
1996	122	302.27	421.68	200.6	120.08	1044.6
1997	167	374.97	468.5	274.8	120.08	1239.1
1998	237	397.37	497.3	389.7	141.56	1425.94
1999	292	397.37	532.6	480.6	163.03	1573.6

respectively. Preventive and maintenance costs for a gantry crane, trailer, toplift and transtainer are 4%, 3%, 15% and 8% of investment costs, respectively.

NUMERICAL RESULTS

Parametric Method

As mentioned in previous section, in order to estimate the stochastic production function, Cobb-Douglas function is used as follows:

$$\text{Ln } Y_t = \beta_0 + \beta_1 \text{Ln}(x_{1t}) + \beta_2 \text{Ln}(x_{2t}) + \varepsilon_{it},$$

where Y_t represents the output or number of containers that are loaded/unloaded in a container terminal in year $t (t = 1994 - 1999)$, x_{1t} denotes the total capital costs in year t and x_{2t} denotes the total labor costs in year t. This function is written for each year and then β_0, β_1 and β_2 must be estimated by the least-squares method.

Then, σ and μ are estimated using the following formulae:

$$\sigma^2 = 1/n \sum (\text{Ln } Y_t - (\beta_0 + \beta_1 \text{Ln}(x_{1t}) + \beta_2 \text{Ln}(x_{2t})))^2$$

$$\mu = 1/n \sum (\text{Ln } Y_t - (\beta_0 + \beta_1 \text{Ln}(x_{1t}) + \beta_2 \text{Ln}(x_{2t})))$$

By replacing σ and μ in Formula 6, efficiency is determined. For example, the Cobb-Douglas function for 1997, by data on Table 1, is as follows:

$$\text{Ln}(167) = \beta_0 + \beta_1 \text{Ln}(375) + \beta_2 \text{Ln}(468).$$

In this order, the function defined for other years and parameters are estimated:

β_0	β_1	β_2	σ	μ
−0.42	−1.87	2.27	0.337	−0.28

Estimates of the mean technical efficiency Formula 6 indicate that the container terminal at Port Rajaei is about 84% technically efficient.

Nonparametric Method

In order to determine the technical efficiency of the container terminal at Port Rajaei, the DEA method was used under CRS assumption and applied to time series data set from the container terminal covering the period 1994-1999.

A two-input single output production technology is considered. Output is the number of handled containers in 1000TEU. Input no.1 is capital costs and input no.2 is labor costs in Rials (millions).

Data of inputs and outputs are shown in Table 1 which have been used here. Technical efficiency may be calculated for individual years by solving Equation 9 and LINGO software was used for solving LP problems. For example, the LP model for 1997 is as follows:

$$\max E_c = U_1^* 167$$

s.t.

$$V_1^* 375 + V_2^* 468 = 1,$$

$$U_1^* 167 - V_1^* 375 - V_2^* 468 =< 0$$

$$U_1^* 107 - V_1^* 277 - V_2^* 287 =< 0$$

$$U_1^* 100 - V_1^* 302 - V_2^* 328 =< 0$$

$$U_1^* 122 - V_1^* 302 - V_2^* 421 =< 0$$

$$U_1^* 237 - V_1^* 397 - V_2^* 497 =< 0$$

$$U_1^* 292 - V_1^* 397 - V_2^* 532 =< 0$$

$$U_1, V_1, V_2 > 0.0001.$$

The coefficients of variables in the LP model were normalized because of being poorly scaled and then were solve [26]. The value of objective function is efficiency and then mean efficiency was obtained during 1994-1999. The mean efficiency of the container terminal at Port Rajaei during 1994-1999 was 75%.

Productivity or Effectiveness Indexes

The indexes were calculated for the years 1990 -1999 as shown in Table 2.

CONCLUSIONS

Because of the increasing growth of container transportation in the world, PSO must apply a modern strategic planning to increase the trend of container handling in the present and future [27].

Two different approaches, parametric and nonparametric, could be used to determine the efficiency of different departments in a service operation. In the case under study, these approaches have been used to measure the efficiency of a container terminal at Ports Rajaei for the years 1994-1999. In parametric and nonparametric methods, average efficiencies are 84% and 75%, respectively.

Furthermore, productivity indexes of the container terminal are determined, with respect to the goals of PSO and the indexes are shown in Table 2 for the years 1990-1999.

In order to develop productivity indexes and efficiencies, PSO installed two gantry cranes and the number of daily handled containers was increased from 122 TEU in 1993 to 297 TEU in 1994. As can be seen in Table 2, the installation of two other gantry cranes

Table 2. Value of indexes for the container terminal at Port Rajaei.

Index	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
$\frac{\text{No. of handled container (TEU)}}{\text{Annual working days}}$	31	56	142	122	297	276	336	460	653	805
Time consumed for one load/unload (min)								3	3	3
$\frac{\text{Tonnage handled to/from Rajaei}}{\text{Tonnage hand. Rajaei and Dubai}}$								0.44	0.45	0.45
No. of ships attracted	156	252	445	260	525	502	558	782	876	965
$\frac{\text{Total handled container (TEU)}}{\text{No. of container ships}}$	72	81	115	171	205	199	218	213	270	303
$\frac{\text{Annual working days}}{\text{Avg. dwell. days cont. in yard}}$								6.88	7.3	8.1
Avg. ship wait. time (days)					4.3	2.9	2	1.25	1.25	0.8
Avg. ship service time (days)					9.13	7	7	6.99	6.5	4.7
Avg. ship dwell. time in port					13.43	10	9	8.24	6.91	5.49
$\frac{\text{Maintenance cost}}{\text{Tot. terminal container cost}}$	0.1	0.1	0.092	0.07	0.033	0.125	0.115	0.096	0.099	0.1
$\frac{\text{No. of handled containers}}{\text{Capital costs}}$	285.2	374.5	938.2	607.2	388.5	332	404	446	597	736
$\frac{\text{No.of handled containers}}{\text{Labor (man hours)}}$	13.42	24.5	61.4	46.5	89.8	83.6	89.2	122.2	179.6	225.6
$\frac{\text{Container terminal income}}{\text{Capital costs}}$	2.25	5.61	14.07	9.1	8.54	7.3	8.88	9.8	13.1	16.19
$\frac{\text{Container terminal income}}{\text{Labor (man hours)}}$	0.147	0.37	0.92	0.69	1.97	1.84	1.96	2.68	3.95	4.96
$\frac{\text{Value added}}{\text{Income}}$	0.75	0.75	0.89	0.85	0.79	0.73	0.77	0.79	0.82	0.83
$\frac{\text{Operational profit}}{\text{Income}}$	-0.17	0.37	0.71	0.56	0.67	0.5 8	0.61	0.66	0.72	0.75
$\frac{\text{Value added}}{\text{Labor (man hours)}}$	0.11	0.27	0.82	0.59	1.57	1.35	1.5	.12	3.24	4.16

shows that the number of handled containers had 171% growth in 1999 compared to that in 1994.

In order to attract the third and fourth ship generation (panamax), PSO developed dredging activities. As a result, the number of container ships attracted to the port increased from 205 in 1994 to 303 in 1999. Besides waiting time, service time and the docking time of ships in the port decreased.

In general, the policies of PSO have had a considerable effect in promoting productivity indexes and efficiency.

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